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VI. *Seventy Chemical Analyses of Rocks* (*chiefly from the Moray Area*), with Deductions. By W. Mackie, M.A., M.D. (Plate I.)

(Read 20th April 1899.)

Original purpose of analyses in confirmation of results of felspar paper.

Results of another order obtained. These results not new;

but not systematically worked out.

During the early part of last year a series of chemical analyses of the Sandstones of the Elgin area was undertaken with the view of confirming some of the results of my paper on the felspars present in sedimentary rocks, as indicators of the conditions of climate prevailing at the period of deposition of the sediments in which they occur. It was hoped that the proportion of alkalies retained in these rocks, and the amount of water of hydration would be found to vary in the one case directly, in the other case inversely, with the proportion of undecomposed felspars present. While it was found that the results obtained in this connection, with one or two apparent exceptions to be afterwards detailed, generally corroborated the results of that paper, it soon became evident that results of another order were being obtained at the same time. These results, as shown by numerous individual analyses, scattered through geological literature, and which might well be cited in support of the conclusions of the present paper, were not perhaps exactly new, but the points raised have not, so far as the author is aware, received systematic investigation by research specially directed to that end.

To establish definite basis for comparison, a series of crystalline rocks analysed.

Rocks analysed—
13 Granites.
15 Metamorphic rocks.
6 Basic and Acid intrusives.
6 Special rocks.

With a view to a more complete survey of the ground, as well as to provide material for establishing a definite basis of comparison, a series of analyses of the crystalline rocks of the area—and these, it is hoped, will be of interest apart from any deductions that may here be made from them—was also undertaken. These comprise 13 specimens of granites, 15 of metamorphic rocks, 6 basic and acid intrusives in the same, 6 other rocks of special interest in the area, three of the latter being of peculiar fragments found in the Torridon sandstone of Glen Banaisdale, but nowhere, so far as known to the author, to be found *in situ* at least in an unmetamorphosed form in the neighbouring area now.

Sandstones analysed—Torridon, 3; L.O.R., 5; U.O.R.,8; Rep., 5; River Sand, 5; Glacial and Post-Glacial, 5; Sea Sand, 2; Culbin, 1.

The sandstones analysed embrace 3 specimens of Torridon sandstones, 5 from L.O.R. sandstones, 8 from Upper Old Red and 5 from the Reptiliferous; while typical examples of the sand of the 5 principal rivers of the area, 5 of glacial and post-glacial deposits, 2 of sea sand, and 1 of the blown sand of Culbin have also been analysed.

Results of analyses in Clastic group generally confirm results of felspar paper.

In confirmation of the results of my previous paper it appears from the analyses of the Clastic series that the proportions of the total alkalies follow fairly closely the results obtained from the proportions of fresh felspar in the several formations. Thus the Torridon sandstones, which were found to show notoriously fresh felspars, gave on the average 4·61% of alkali, the L.O.R., which followed next in order as regards the proportion of fresh felspars, 3·54%; the U.O.R. 1·87%, and the Reptiliferous, as in that case also the lowest with 1·66%. Then of more recent deposits, the glacial and post-glacial were found to contain a preponderance of fresh felspars, and are represented in this series by 3·3% of total alkalies; the river and sea sand, as in that case, follow in order with 2·88% and 1·85% of total alkalies respectively, the series being closed by the blown sands of Culbin with 1·89%.

These results may be conveniently put in tabular form thus:—

Torridon sandstones . .	4·61 %	of alkalies retained.
L.O.R. „ . .	3·54	„ „
U.O.R. „ . .	1·87	„ „
Reptiliferous sandstones . .	1·66	„ „
Glacial and Post-Glacial deposits	3·37	„ „
River sands . . .	2·88	„ „
Sea sand	1·85	„ „
Culbin sand . . .	1·89	„ „

Apparent exceptions.

It will be remembered that the river and sea sands showed a proportion of kaolinised felspars greater than the U.O.R. or Reptiliferous sandstones. They, however, show a higher percentage of alkalies. This, I think, may be explained on the supposition that it is only the surface of the felspar particles—which are also perhaps in slight excess in number in the case of the recent sands, that have had time to undergo the kaolinising process. This is further borne out by the fact that they also retain a very much higher proportion of soda relatively to the percentage of the potash present, than do any of the sandstone groups.

Hydration results too often complicated with CO_2 and uncombined H_2O to be of value.

The results from the point of view of hydration have been too often found to be complicated with carbonic acid determinations as well as uncombined moisture to be of any value in this connection. They have therefore been discounted.

Divisions of subject matter.

For greater facility of treatment the subject matter of the present paper is dealt with under the following headings:—

(1) Remarks on peculiarities of individual or group analyses.

(2) Instances of probable interchange of substances between igneous and metamorphic rocks where in contact.

(3) The loss of lime, and to a less extent of magnesia, originally existing as silicates in the igneous and metamorphic rocks in passing from these to the sedimentary rocks in the process of denudation. Carbonate of lime present in the latter is of course discounted as a secondary infiltrative or at least derivative product.

(4) The loss of alkalies generally, and in particular the marked loss of soda relatively to the potash shown by the sedimentary rocks as compared with the proportions originally present in the crystalline rocks.

(5) The bearing of these results on the question of the probable origin of certain of the metamorphic rocks, with discussion of the points from a chemical point of view that make for establishing a sedimentary origin, as against the points that make for establishing an origin from previously existing igneous rocks.

(6) Inferences as to origin of metamorphic rocks in particular cases, with some criticism of existing theories.

1. *Remarks on Individual or Group Analyses.*

Granites—Stratherric granite.

Among the granites the Stratherric rock calls for some remark. The specimen analysed was from a quarry by the roadside on the east side of Glen Liath (Inverness-shire), and showed to the naked eye free quartz, hornblende, biotite, more than one generation of felspars, and sporadic crystals of sphene of some size. In many specimens of this granite no free quartz appears to the naked eye, and the rock becomes a true syenite. Quartz, however, appears in small amount under the microscope, with abundant orthoclase and plagioclase felspars, and numerous fine apatite needles. The analyses shows it to be far from a typical granite—a silica percentage under 60% being quite exceptional in a granite. Another somewhat basic granite is the

Ruthrie Granite, Aberlour.

Ruthrie rock. This shows in addition to the normal constituents occasional crystals of sphene and abundant plagioclase felspar. Apatite, as shown by a phenomenally high phosphoric acid determination ·41%, is present in abundance.

Two groups of Granites—Grey and Red. Characters of Grey group.

Lime percentage in Abriachan granite—possible explanation.

The granites, as a whole, fall into two groups—the Grey and the Red. The former embraces Stratherric, Loch Moy, Ruthrie and Rubislaw granites. They are decidedly more basic as a class than the Red, showing as they do an average silica percentage of 66·94%. They are also richer in iron oxides, which reach 4·475% estimated as ferric oxide, or nearly twice the average over all. They are also richer in lime, showing 2·43% as against 1·50% for the whole. Only one of the red rocks approaches or exceeds this figure, that is the Abriachan rock with 2·61%, but I am reminded that this granite has been intruded in an eminently limestone region, and that this circumstance may account for the peculiarity here indicated.

Characters of Red group—Hyperacidity.

Red a more natural group than Grey—may have been derived from one magma.

The red group as a whole is characterised by more than average acidity—several of its members showing over 75% of silica. Another isolated silica determination of the Benrinnes rock not given in table reached 75·32%. They also show a low—in the case of Kinsteary granite a phenomenally low—percentage of iron oxides (·68%). In several instances the percentage of lime is excessively minute, while in some the magnesia percentage practically vanishes. The red rocks make a much more natural group than the grey. In fact there would not appear to be anything very extravagant in the assumption that they have all been derived from one magma. What differences are observed might in such case be ascribed partly to slight differences in the proportions of quartz and felspar in the specimens taken for analyses, partly to local differences in the strata among which the several masses have been intruded. An analysis of the Peterhead rock by J. A. Phillips as illustrating the characteristics of the group has been included with the others. No such generalization could possibly be maintained with regard to the grey rocks here brought together, though they are probably not all of them isolated occurrences of the magmas they represent. If the Stratherric rock were to be correlated with any of the other rocks of the series analysed, it would rather be with the eastern diorites. The occurrence of diorites as intrusives in the rock masses bounding this granite, with a chemical composition not unduly dissimilar to either, make this suggestion not altogether an improbable one.

Netherly diorite. Progressive acidity from centre to periphery of boss.

Of the diorites, the three analyses from the Netherly boss indicate a progressive acidity in this mass from centre to periphery. The same conclusion is borne out by microscopic examination of sections from the different zones.

Portsoy Serpentine —High Phosphoric Acid, ·81%.

The single analysis of serpentine from Portsoy calls for remark in respect of the unique proportion of phosphoric acid, ·81% present. The result was confirmed by re-determination.

Quartz-porphyry of Craig-an-oan—probable parent rock of fragments in U.O.R. sandstones.

The analysis of the quartz-porphyry of Craig-an-oan is important as the probable parent rock of some of the pebbles present in the U.O.R. sandstones of the Elgin area, as at Newton and Scaat Craig. Confirmation is thus gained of the conclusion arrived at on other evidence of the western origin of much of the debris of these sediments.

Rock fragments from Torridon sandstone.

Some importance is attached to the analyses of fragments of banded, flinty-looking rocks, in some respects simulating rhyolites from the base of the Torridon sandstone in Glen Banaisdale, Ross-shire. They may be of some theoretical interest in view of the question of the origin of the eastern or younger gneisses of the Highlands.

Remarks on Metamorphic rocks postponed.

What observations fall to be made on the analysis of the Metamorphic rocks will naturally come up when the question of their origin is considered.

Sandstones—Progressive rise in SiO_2 percentage from early to later times.

Ferric oxide decreases from early to later periods.

Relation of oxides of manganese to presence of carbonate of lime.

The Sandstone analyses show a general tendency to a progressive increase in their silica percentages from earlier to later geological periods, culminating in 89·75% as the average of the Reptiliferous group. This general result is, however, obscured to some extent by the presence of large quantities of carbonate of lime as a secondary infiltration product, more particularly in the L.O.R. and U.O.R. rocks. A decrease in the amount of ferric oxide from early to later formations is an equally conspicuous feature. Oxide of manganese, which in the case of the sandstones has been uniformly reported as per-oxide, shows a decided relation to the presence of carbonate of lime. This is easily explained when the tendency of carbonate of lime to precipitate soluble manganese salts is re-

L.O.R. of Foyers.

Disappearance of lime and retention of ferric oxide of original granite.

Relative increase of silica and alkalies.

River sands—little loss of phosphoric acid.

Inference.

membered. Of the individual analyses the Foyers L.O.R. specimen, when taken in conjunction with the analysis of Stratherrie granite, from which it had almost exclusively been derived, brings out, when the carbonate of lime is discounted, in a remarkable manner, the fact that the lime originally present as a constituent of the hornblende and plagioclase felspars of the granite has almost entirely disappeared, while the ferric oxide has been in great part retained. The apparent increase in the silica and total alkali percentage from the carrying away of the ferro-magesian and other susceptible constituents is also noteworthy in this case. In connection with the analyses of river sands, attention may be directed to the fact that where phosphoric acid determinations have been made, little decrease, if not in some cases a substantial relative increase, has taken place from what obtains in the crystalline and metamorphic rocks. This would appear to indicate that the mineral apatite is not readily decomposed under the present atmospheric conditions.

Chlorine determinations in the several groups.

Often with phosphoric acid in proportion to form apatite.

Over all an excess of chlorine.

Inference—other sources of chlorine.

As will be seen by a reference to the tables of analyses a number of chlorine determinations have been made in a proportion of the analysis of each group. These all over perhaps show a less percentage of this element than many determinations—chiefly, however, in the case of recent volcanic rocks—than might be quoted from geological literature. Some of my earlier determinations were equally high; but this resulted from neglecting to see that all filter papers used which had naturally been extracted with dilute hydrochloric acid—were washed perfectly free from chlorine before use. These analyses were, of course, discarded. Where a phosphoric acid determination accompanies the chlorine determination it will be found that the proportions of the two correspond more or less closely to those required by the formula of apatite—in one or two cases almost exactly so, *e.g.*, Ruthrie granite. Over all, however, there is a preponderance of chlorine, so that apart from the fact that in the mineral apatite a portion of the chlorine may be replaced by fluorine, we would naturally infer that there are usually other sources of chlorine besides apatite.

Interest of chlorine determinations in relation to saltness of the sea.

These chlorine determinations are of theoretical interest in relation to the origin of the chlorine in sea water, and were made expressly with the view of attacking the problem—whether chlorine exists in sufficient quantity in the rock systems of the crust to account for the present saltness of the sea.[1]

II. *Interchange of Substances between Igneous and Metamorphic Rocks in contact.*

Granite vein, Craigellachie Bridge.

Of the transference of substances from igneous to metamorphic rocks and *vice-versâ*, when in contact, we have the case of the granite vein at Craigellachie Bridge and the metamorphic rocks underlying it. Analyses of this granite and of two specimens of the rocks immediately underlying it have been made. The granite vein undoubtedly belongs to the Benrinnes series of granite intrusions, and like these might be expected to show a low percentage of lime, but in this case we have a percentage which, with one exception, viz., Abriachan already hypothetically explained, is the highest of the series of red granites. Its iron oxide percentage ranks with Kinsteary granite as the lowest in the series, while the amount of magnesia is recorded as a mere trace. There is here indicated, I think, a passage of lime compound inwards into the vein and of the ferro magnesian compounds outwards into the surrounding rocks. This is borne out by the percentage of lime in the two examples of the

High lime, low magnesia, and iron-oxide percentages.

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[1] In a paper read before the Inverness Scientific Society and Field Club, on 14th March last, I have shown, on the hypothesis that the ocean started as a body of fresh water, and that all the chlorine in the chlorides of sea water had been derived from the liberation of chlorine from the rocks of the crust, which, according to the analyses made, average ·06°/o, it would require the denudation of over 500 continents, equal to the present land masses, to supply the requisite amount of chlorine; five million years being taken as the time required for the denudation of 900 feet, the supposed average height of the continents, the sea would require 2500 million years to reach its present saltness, and this without taking note of the amount of salt that has separated from its waters in the solid form throughout geological time. The result may be taken as a *reductio ad absurdum* of the position that the sea did start as a body of fresh water, and the conclusion is drawn that it had become salt long before the dawn of life on the globe, and that by the operation of causes now unknown to us.

In the same paper reasons are given for believing that sufficient soda has not yet been found in the process of rock decomposition to unite with all the chlorine present in sea water—that is to say that chlorine is actually in excess of sodium. This is the more remarkable as the waste of soda all over, as deduced in another part of this paper, is equal to 1·65°/o by weight of the rock masses denuded, while the chlorine can only reach ·06°/o of the same. The inference therefore, that there have been other sources of chlorine than the rock rind of the earth, seems warranted in the circumstances.

rock in contact that have been analysed coming out lowest among the local rocks, while the magnesia percentages of the same specimens are among the highest. Of the transference of the alkalies there is no direct evidence, though the high percentage of potash in one of them would appear to indicate the transference of potash compounds from the granite to the contact rock, that is from the less to the more basic, as appears to have happened in other instances presently to be referred to. It is also worth noting—whatever interpretation may be attached to the fact—that this granite shows a higher percentage loss on ignition than the whole of the granite series with the single exception of the Stratherric rock.

Rocks in contact—low lime, high magnesia percentages.

In this connection, and as evidently bearing some relation to the facts just noted, it may be mentioned that two series of granite veins are seen intersecting the schists on the Rothes Burn, three or four miles to the north. The members of the one series are coarsely crystalline and show muscovite to the total exclusion of biotite as their mica. In some of these veins garnets occur, chiefly along their marginal zones. The members of the other series of veins are finely crystalline, and have biotite to the exclusion of muscovite as their mica. No garnets appear in these. They are very hard and splintery, and present the appearance of having undergone rapid chilling. Two questions arise in this connection. Did the former set make their appearance at a time when the containing rocks were in a condition likely to facilitate free osmosis, and thus to admit of the easy passage of the ferro-magnesian compounds outwards and the lime compounds from the containing rocks, in which as several analyses show they exist in abundance, inwards to form the garnets there observed? And were the second series, on the other hand, intruded at a time, presumably a later time, when the condition of the rocks in contact practically prevented any such interchange?

Two series of granite veins in the neighbouring schists.

Facts indicating interchange in one series, not in other.

Question of different ages.

In the case of the hornblende schist (7 ϵ) in contact with one of the veins of the former series we have a rock contrary to what is normal in basic igneous rocks, showing a slightly higher percentage of potash than soda. Is the proximity of a rock rich in potash to be held responsible for the result?

Basic igneous rock with abnormal soda-potash relation.

In one of the analyses of the local diorite (1 β) the same relation holds—a higher potash than soda percentage in a basic rock. The fact that this has happened at the margin of the boss, where, as shown by the microscope, biotite is abundant, and plagioclase felspars relatively scarce, may be held to sufficiently account for the result obtained.

Same relation at margin of diorite boss.

These observations, which may be taken as a bye-product of the research proper, seem to be sufficiently interesting in themselves to be worth recording. They might fitly, however, be made the subject of further research.

Observations call for further research.

III. *Loss of Lime and Magnesia as Silicates in the Clastic Series.*

The average of all the lime determinations of the granite analyses is 1·5%, of all the metamorphic rocks 2·56%, or quite 1% more, while in the case of the basic rocks it reaches 7·12%. Over the whole of the igneous and metamorphic rocks, together we get the average of 2·94%. This figure may fitly be taken as a sort of standard by which we may gauge the loss of lime that has taken place in the sedimentary rocks under the operation of the surface agencies in the process of denudation.

Average percentage of lime in the various groups.

Average over whole Crystalline series 2·94%

In the Clastic group we have in the case of the Torridon sandstones, as the average of three analyses, ·24% of residual lime, whether existing as silicate or as carbonate. That this result is not due to any want of lime in the rocks from which the Torridon sandstones have been derived is shown by the average of four Archæan rocks taken at random, showing 4·75% of lime. This average may not be representative of the proportions of lime present in the Archæan rocks taken as a whole, but it serves to show that there is no lack of lime in the rocks out of which the Torridons have been largely built up. The result, therefore, so far as the latter rocks are concerned, is certainly somewhat surprising, showing as the Torridons do the lowest percentage of residual lime of the whole Clastic series. In this connection it is worth recording that while there is almost everywhere abundant evidence of the derivation of the Torridons from the more acid of the Archæan rocks, there is little or no evidence, so far as my observation goes, except locally at Gairloch in the presence of fragments of the green schist (2 ϵ), of their derivation from the more basic rocks of that series, though it is very evident that

Torridon sandstone ·24% of lime.

Not due to want of lime in the Archæan rocks from which derived.

Torridons show lowest percentage of whole Clastic series.

Ferric oxide of basic Archæan rocks retained in Torridons, lime carried away.

they were an equally prominent feature in the Archæan system then as now. The markedly high percentage of ferric oxide in the Torridon specimens analysed (4·48%, as against 2·95% for the L.O.R.) proves conclusively I think, that these basic igneous rocks contributed their quotum of ferric oxide to the residual Torridon debris, while their lime was carried away in solution, and so lost as a tangible entity in the rocks then in course of formation.

Result important in relation to question of climate of time.

It is manifest that these considerations must be steadily kept in view in any inquiry into the probable climate that prevailed in Torridon times. The carrying away of so much lime in solution, it may be remarked, necessarily implies considerable aqueous precipitation, and consequently is a fact opposed to one particular theory of the climate of the time.

Passing to the L.O.R. and succeeding sandstone groups, after discounting the amount of lime necessary to combine with the carbonic acid present, we have in apparently ascending series the following averages—

Ascending series of residual lime percentages.

3 Torridon Sandstones (less than)	·24 %	(lime retained).
4 L.O.R.	·63	,, ,,
7 U.O.R.	·67	,, ,,
5 Reptiliferous	·96	,, ,,
5 Glacial and Post-Glacial deposits	1·14	,, ,,
5 River Sands	1·28	,, ,,

The defect from 2·94%—a fair measure of the activity of agents that attack lime silicates in each case.

These agents acted more intensely in early times, with gradual decrease since.

These percentages we have as against 2·94% which may be taken as a fair all round average of the amount of lime existing as silicate in the rocks from which these sediments were presumably derived. The balance in each case must be set to the credit of the particular agent or agents that attack lime silicates, and consequently if the numbers representing the several geological periods be subtracted from 2·94%, the remainder in each case would represent in a general way the measure of the intensity of action of these agents during the respective periods. The results would go to show that they acted more intensely in the earlier geological periods, and that their action has been gradually waning in intensity ever since. Now carbonic acid is the agent that *par* *excellence* attacks lime silicates. It would therefore follow that the amount of carbonic acid in the atmosphere has been slowly decreasing, or that some circumstance has been rendering it less effective in its action in later geological times. A gradual diminution of the amount present in the atmosphere would most readily meet the case. That such has very likely been the case will not, I think, be seriously disputed by geologists, if put as a general proposition.

Probable decrease of amount of CO_2 in atmosphere.

Investigation by Geological Survey of Kentucky.

Earlier limestones richer in Na_2O, P_2O_5 and CaCo$_3$ etc.

Converse probably true as regards other deposits.

Here shown to hold good for CaO.

Proportion of P_2O_5 in river sands in keeping with result.

As confirming in a remarkable manner the conclusion just arrived at, the result of an investigation carried out by the Geological Survey of Kentucky may be here quoted. They find as the result of numerous analyses of limestones of all ages, that the older limestones are, as a general rule, richer in soda, phosphoric acid, and, where non-magnesian, also in lime carbonate, than are the younger and more recently formed, and that they are correspondingly poorer in silica and insoluble silicates. Conversely, if they had examined the other sedimentary deposits from which presumably the material of the limestone had been extracted, we should expect that they would have found, as a general rule, the earlier deposits poorer in soda, phosphoric acid and lime than the more recent. This is exactly what we have shown to hold good in the case of lime, and we shall presently see that it is no less true for the soda. As regards the phosphoric acid, though that has not been made the subject of special investigation, it is interesting to note in this connection that the relatively large proportion found present in the river sands examined is a result quite in keeping with that indicated above.

Magnesia follows same law.

Some apparent anomalies.

Magnesia follows in a general way, though perhaps in a less marked degree, the same law as the lime, though, I think, that some peculiarities of the conditions of deposit account for some irregularities in this case. The comparatively high result obtained for the Torridon is due to a freak of one of the specimens analysed, where the magnesia was evidently present as a secondary infiltration product in the form of a hydrated silicate. The fact that the Reptiliferous is here less than the U.O.R. series may be ascribed to the former set of beds having been accumulated by wind, which would naturally eliminate the fine scales of biotite, from which presumably the magnesia has in large part been derived.

IV. *The Loss of Alkalies, particularly of Soda.*

Proportion of alkalies in rocks from which sediments derived.

Fixing of a standard.

In order to deal with the question of the proportions of residual potash and soda present in the sedimentary rocks in a more effective way, it is desirable first of all to determine more or less precisely the proportion of these substances, both relatively and absolutely, which exist in the rocks from which the sediments in question have been derived. It is manifest that this cannot be done with any degree of precision in every case, but if we take the averages of a number of determinations of rocks of presumably similar character we shall probably reach a result which will be found not to deviate very far from the average, and be likely to afford a standard which at any rate shall be fairly adequate for comparative purposes. In this case I propose to take the average percentage of alkalies over all the analyses of rocks other than the sedimentary rocks themselves which accompany the present paper.

Average of alkalies in granites.

Average in metamorphic rocks.

Average in basic igneous rocks.

Average of alkalies all over. Potash-soda relation.

The average of the thirteen granites shows as regards the alkalies 4·27% potash and 2·81% soda—total 7·08%, with a relation of potash to soda of 1·52 to 1. The average of eleven analyses of granites by Haughton shows 5·11% potash with 2·79% soda — total 7·90% alkalies, with a relation of 1·84 potash to 1 soda. Of nine other analyses of granites which I have been able to collect, the average was 4·23% potash and 3·53% soda, giving a total of 7·76% alkalies with a relation of 1·18 potash to 1 soda. These two latter series together give an average of 7·80% for total alkalies with a relation of 1·54 potash to 1 soda, or a relation substantially the same as that deduced from the series given in the present paper. The fifteen analyses of metamorphic rocks give an average of 2·41% potash to 2·20% soda—total 4·61%, with a relation of 1·09 potash to 1 soda, while the basic intrusives give an average of 1·18% potash to 1·83% soda—total 3·01% alkalies, with a relation of ·64 to 1 soda. Eleven other diorites collected from geological literature gave a relation of ·55 potash to 1 soda. Over all the analyses of the present paper we have potash 2·98%, soda 2·26%—total 5·24%, with a relation of 1·32 potash to 1 soda. These figures are therefore set up as a general standard for comparison. But we should reasonably expect that where a series of sediments have been exclusively derived from granite, they would, in the absence of any leaching out of alkalies from the action of subaerial or sub-

Proportion of alkalies necessarily vary with rocks from which sediments derived.

aqueous agencies, show a considerably higher potash and soda average, and also a somewhat higher potash relatively to the soda percentage than that presented by the figures given—that is to say, they would approximate more closely to the averages for the granites. If on the other hand they were derived exclusively from metamorphic rocks we should expect a somewhat lower percentage of total alkalies with a relation between the soda and potash more nearly balanced. While if exclusively derived from basic igneous rocks a still lower percentage of total alkalies, but a considerable excess of soda over potash. If from a mixture of all these the figures just given would represent what might naturally be expected in the circumstances. The figures given as averages of each of the rock groups might in case of exclusive derivation from that particular kind of rock be taken as representing in a general way the upper limit of expectation in each case.

Upper limits.	Upper Potash Limit.	Upper Soda Limit.	Total Alkalies.	Potash-Soda relation = $\frac{K_2O}{Na_2O}$
Sediments exclusively derived from granites . .	4·27	2·81	7·08	1.52
Do. metamorphic rocks .	2·41	2·20	4·61	1·09
Do. basic igneous .	1·07	1·83	2·90	·64
Do. mixture of all these .	2·94	2·26	5·20	1·32

Torridon sandstones K_2O 4·20°/₀ Na_2O ·36°/₀ $\frac{K_2O}{Na\ O} = 11·8$.

Now in the case of the Torridon sandstones, which have largely been derived from the denudation of the Archæan rocks, which are chiefly acid granitic or gneissic rocks, though containing a large proportion of basic intrusives, show in the analyses which have been made 4·25°/₀ of potash and only ·36°/₀ of soda. That this result is not due to any lack of soda in the rocks from which they have been derived the following average of the four Archæan rocks taken from the series here given will show:—

CaO 4·75°/₀; MgO 3·76°/₀; K_2O 2°/₀; Na_2O 2·27°/₀.

While this may not represent the fair average yield of alkalies of the Archæan rocks, it shows at least that a fair amount of soda might reasonably be expected. Instead of that we have the soda down to ·36°/₀ or less than $\frac{1}{11}$ part of the potash. No doubt there is in the case of the Torridon average an apparent increase of the potash relatively to the other constituents from the leaching out of the more soluble substances, but the disparity between it and the residual soda is sufficiently emphasised to require explanation, and this has, no doubt, been due to the relatively greater chemical susceptibility and consequently greater solubility of the soda compounds under the particular conditions of climate then prevailing.

Due to greater chemical susceptibility of the soda compounds.

The relation between the soda and potash seen in the case of the Torridon sandstone is by no means unique, though it is more pronounced taken over all than in any of the sandstone groups that follow. In the L.O.R. sandstone and conglomerates, which except locally on the shores of Loch Ness, have largely been derived from the waste of metamorphic rocks, we get an average relation of 4·3 parts potash to 1 soda—the average for the metamorphic rocks being 1·09 K_2O to 1 Na_2O. In the case of the Foyers conglomerate, we have again a relative increase in the amount of potash, compared with what obtains in the analyses of the granite from which it was derived, in consequence of the operation of the causes already noted, but the relation of potash to soda is as 1·11 to 1 in the granite and as 2·61 to 1 in the conglomerate. Again, in the U.O.R. rocks, which in another paper I have given reasons for believing have been more largely derived from granite than the L.O.R.[1] The potash-soda relation rises to 5·5 to 1 all over, though some of the individual analyses indicate a relation of nearly 14 to 1. In the Reptiliferous the relation, for some reason or other, becomes more equally balanced, though the difference is still pronounced—potash being as 2·76 to 1 soda. Still, on the whole, the total amount of alkalies retained has suffered considerable decrease. Some difference in the conditions of deposit probably accounts for this, though differences of climate may have also had their share. Their subaerial origin may be cited as in part accountable, and in this connection it is interesting to note that among recent deposits the Culbin sands are found to retain the largest amount of soda, relatively, to the potash present.

L O.R. $\frac{K_2O}{Na_2O}=4{\cdot}3.$

Foyers conglomerate—
$\frac{K_2O}{Na_2O}=2{\cdot}61.$
Stratherric granite—
$\frac{K_2O}{Na_2O}=1{\cdot}11$

U.O.R. $\frac{K_2O}{Na_2O}=5{\cdot}5,$
but individual analyses
$\frac{K_2O}{Na_2O}=14.$

Reptiliferous—
$\frac{K^2O}{Na^2O}2{\cdot}7.$

Differences in conditions of deposit as well as of climate accountable.

Culbin sands show similar relations among recent deposits.

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[1] Sands and Sandstones of Eastern Moray, "Transactions," Vol. VII., Pt. iii., p. 148 ; also "Sand Grains and what we may learn from them." Elgin 1894.

Peculiarity of results in case of Torridon and U.O.R. of Newton.

The results obtained in the case of the Torridons and the U.O.R. of Newton are especially noteworthy. As both of these were found to be characterised in a special degree by the prominence in them of remarkably fresh felspars, one would naturally in such circumstances have expected a relatively high percentage of soda. The operation with special intensity of some particular agent or agents which made for the elimination of the soda-bearing felspars must in each of these cases be presumed.

Recent clastic groups—glacial and post-glacial richest in alkalies.

Chemical action under glacial conditions.

Passing now to the analyses of elastic materials of recent date, we find that the glacial and post-glacial are richest in alkalies; but even here, under the operation of agencies which we should naturally expect to rank as mechanical, there is a sensible loss of soda as compared with the potash. Apparently, therefore, we are not in a position, even under glacial conditions, to entirely discount chemical action. No doubt a proportion of the debris that has gone to make up these deposits has been derived from the sandstones of the area; but it may be reasonably doubted whether this is responsible for the total result observed.

River sands.

Result in debris of basic igneous rocks.

The river sands retain a fair proportion of alkalies, and the difference between the potash and soda is here less marked, though there is still some undoubted loss of soda relatively to the potash. The sand of the Deveron was purposely chosen as likely to illustrate the effect of chemical agencies on the waste of basic igneous rocks in relation to the elimination of their alkalies. The fact that the specimen of this sand analysed showed 3·26 times as much potash as soda would appear to indicate that under present-day conditions the waste of these rocks is not likely to affect the debris of which they form a part with the prevailing characteristic of such rocks—that is, an excess of soda over potash.

Raising of soda relatively to potash by carrying away of potash-bearing micas.

The sample of sand from the Findhorn taken in conjunction with the analysis of Ardclach granite, from which it has at this point been mainly derived, shows that the relation of the soda to the potash may be temporarily raised in the debris resulting from rock disintegration by the carrying away of potash-bearing micas, as has undoubtedly happened here.

Of the two specimens of sea sand only one—that from Lossiemouth—may be regarded as typical. It shows an advance on the river sands as regards the elimination of both soda and lime. The other analysis of sea sand was of a sample specially chosen for the purpose of ascertaining the possible relation of the alkalies in the waste of basic igneous rocks. Here, as in the specimen of river sand, there is a preponderance of the potash alkali over the soda, contrary to what is found to prevail in basic igneous rock masses previous to denudation.

Sea sand.

Another case of basic igneous waste.

The blown sand of Culbin has been already commented on in connection with the Reptiliferous sandstone. It shows a relation of 1·7 potash to 1 soda—that is to say, the highest relative amount of soda of any of the clastic groups. Still, that is considerably above the standard 1·3 potash to 1 soda. All over, therefore, there is a pronounced waste of the soda compounds relatively to the potash, and in not a single analysis out of the 34 examples of clastic material analysed has the soda ever exceeded or, indeed, even very closely approximated the potash in amount.

Highest relative amount of soda in Culbin sand.

No case in clastic group of soda exceeding potash in amount.

The results all over for the clastic group may be conveniently summarised in tabular form thus:—

Average of—	Lime.	Magnesia.	Potash.	Soda.	Potash / Soda.
3 Torridon sandstones	·24	1·06	4·25	·36	11·8
5 L.O.R.	·63	·19	2·87	·67	4·3
8 U.O.R.	·67	·32	1·58	·29	5·44
5 Reptiliferous	·96	·17	1·22	·44	2·76
5 Glacial and Post-Glacial	1·14	·56	2·34	1·03	2·27
5 River Sands	1·28	·53	1·93	95	2·03
2 Sea Sands	...	...	1·25	·60	2·08
1 Blown Sand	...	...	1·19	·70	1·7
Average of 34 clastic specimens	·98	·42	2·08	·61	3·37
Expectations in absence of operation of lowering agencies	2·94	1·85	2·98	2·26	1·32
Loss, presumably by solution	1·96	1·43	·90	1·65	...

That is to say, $\frac{2}{3}$ of the lime, $\frac{7}{9}$ of the magnesia, about $\frac{2}{7}$ of the potash, and slightly more than $\frac{5}{7}$ of the soda has vanished; from which it would be inferred that the lime, magnesia, and soda silicates are not very dissimilar as regards chemical susceptibility, while the potash compounds are much more refractory than any of them. It has to be borne in mind,

Losses of lime, magnesia, potash, and soda all over.

however, that as regards the lime the above result does not include lime existing in rocks as carbonate, but only as silicate. To the solubility of lime previously existing in rocks as carbonate must therefore be attributed the marked excess of lime over alkaline salts in natural waters, but the direct decomposition of lime silicates has, no doubt, yielded a large, but still apparently subordinate, proportion.

Above result does not include lime previously existing as carbonate.

It might be contended that the loss of lime, magnesia and alkalies from the sandstones is the result of post-depositional changes—that is to say, has been due to water percolating through them for prolonged geological periods, and carrying off these substances in solution. While it is impossible to deny that such action has to some extent taken place, there are good reasons for believing that the loss from this cause has over all been insignificant. Such a cause would have operated on the crystalline rocks as well, and though it is true that these are incapable of holding as much water in their interstices as the clastic group, on theoretical grounds we should suppose it is the rate of change of such water rather than its quantity that is the main factor in any such action. The presence, again, of felspars of unwonted freshness in many sandstones, *e.g.*, Torridon and Newton U.O.R., does not warrant the belief that this action has, at least in these cases, been of much consequence, while in the open textured sandstones of the Reptiliferous the disparity between the amount of potash and soda is less marked than in any of the other sandstone groups. The presence of ferric oxide in quantity in many of the sandstones, *e.g.*, Torridon and L.O.R., would in effect be preservative against such action, while the presence of large quantities of carbonate of lime in others, such as the L.O.R. generally, and Scaat Craig in the U.O.R., would also act in the same way, and its presence in these cases might be taken as indicating that the percolating water was in their case depositing substances already held in solution rather than dissolving fresh ones. After the deposition of the lime carbonate little further change in the soluble constituents of the sandstones could be expected to take place. The conclusions of my felspar paper are necessarily founded on the general assumption that post-depositional changes have been insignificant and any observed changes have been there noted.

Cause of loss of lime, magnesia and alkalies may possibly be post-depositional.

Reasons for thinking such actions insignificant.

V. *Bearing of Results on the Question of Origin of the Metamorphic Rocks.*

Possible views as to origin in light of results in clastic rocks.

If we compare the averages obtained from the analyses of the metamorphic rocks with those obtained in the case of the purely clastic specimens as a whole, only one or two, or at most three, positions as regards the origin of the former, can possibly be maintained.

Not all of sedimentary origin.

If so, subaerial conditions must have differed.

These may be briefly put—(1) either the metamorphic rocks have not all of them taken origin from sedimentary rocks; or (2) if they have, the conditions regulating subaerial waste must have been very different at the time of their deposition from those prevailing before or since. During Torridon times, which we know preceded one period of metamorphism, these only differed in degree from what obtained in the subsequent geological periods; or (3) if they have had a sedimentary origin and similarity of conditions is presumed, some means of restoring the alkalies as a whole, and of the soda in particular, during the metamorphic process must be presupposed.

If conditions similar, lime and alkalies must have been restored—how?

Restoration of lime possible.

The same difficulty would also have to be faced with regard to the lime, though in that case the difficulty might be got over by supposing a portion of the lime may have existed as carbonate in the previously existing sediments, just as it does in sedimentary rocks at the present day, and that this had by meeting with other substances present been subsequently reconverted with loss of carbonic acid into compound lime-silicates, as has undoubtedly actually happened in the case of some crystalline limestones, and of which the pyroxene in the Tiree marble may be cited as a conspicuous example. But it is manifest that no theory which does not at the same time explain the restoration of soda need be considered here. Any attempt at explanation on such grounds may, therefore, be given up, and we appear meantime to be shut up to the conclusion that the true position is—that the metamorphic have not all of them been derived from previously existing sediments, but that the truth evidently lies midway, that is, that part have been derived from sedimentary, part from igneous, rocks. And on the strength of these analyses, when looked at in the light of the results obtained from the analyses of igneous as against the

Conclusion that they are partly of sedimentary, partly of igneous origin.

analyses of clastic rocks, a fairly reliable answer can be given to the question of origin in a large proportion of cases.

Points relied on to prove a sedimentary origin.

The points from a purely chemical point of view that may be relied on to prove a sedimentary origin of metamorphic rocks are the following—

(1) A silica percentage over 78%.
(2) An alumina percentage under 11%.
(3) A low percentage of lime.
(4) A low percentage of total alkalies; and particularly
(5) A very low percentage of soda relatively to the potash present.

Indications of an igneous origin.

As regards origin from an igneous rock the following may be noted as indications—

(1) A silica percentage not above 78%.
(2) An alumina percentage not under 11%.
(3) A lime percentage varying according to basicity, and which may be almost zero in the case of acid rocks, but is always relatively high in the case of basic rocks.
(4) A high percentage of total alkalies—the soda not in marked deficiency relatively to the potash in the case of acid rocks, or the total alkalies low or moderate in amount, but the soda in excess of the potash in the case of basic rocks.
(5) The total facies of the analysis in so far as it resembles typical analyses of well-known types of igneous rocks.

VI. *Inferences as to Origin in Particular Cases.*

6, 13, 15 (ε) of sedimentary origin.

Applying these canons to the analyses of the metamorphic rocks given in the present paper, and taking the potash-soda relation as the most important first, we pick out 6, 13, 15 (ε) with a high relation as undoubtedly of sedimentary origin. This selection is confirmed by each of these showing a low percentage of lime, *e.g.*, ·63, ·26, ·45% respectively. No. 6 to the naked eye, is seen to be of clastic origin, and judging from its appearance, containing as it does large angular fragments of different felspars, as also from its analysis, we should conclude that it has been largely derived from the denudation of granite.

Gneiss? Craiganoun of clastic origin.

1 and 2 (ε) of igneous origin.

On the other hand, from the low potash-soda relation, we pick out (ε) 1, 2 as of undoubtedly igneous origin. These two must also be admitted to this group on account of their high lime percentage, while

4, 5 (?) 7, 8, 9 (?) also igneous.

Green schist, Gairloch shows analysis of typical basalt.

4, 5, 7, 8, 9 (ϵ) must be admitted on account of their high lime percentage as well as for their total and relative percentage of alkalies, though 5 and 9 may be marked as somewhat doubtful. No. 2, it should be noted is the analysis of a typical basalt, and, as such, is of some theoretical interest in connection with the occurrence of basic intrusives in the Archæan series.

11 and 12 (ϵ) doubtful.

10 and 14 (ϵ) fulfil igneous canons, but doubtful.

Of the remainder, 11 and 12 (ϵ) must be marked doubtful for reasons already given, that is, on account of secondary infiltration from a mass of acid igneous rock. Nos. 10 and 14 (ϵ), so far as analyses go, might very well have been originally acid igneous rocks. If not directly derived from such rocks, they must certainly represent debris derived from such rocks, whether igneous or basic, without much leaching out of the original lime or alkalies.

3 (ϵ) Glen Docherty Schist of Sedimentary origin.

But not metamorphosed Torridon.

May be metamorphosed 1, 2, 3 (δ).

No. 3 rather falls into sedimentary groups by reason of its high silica and low alumina percentage, but it is just possible that this may be due to siliceous infiltration or leaching out of its more soluble constituents previous to metamorphism. Compared with the Torridon sandstone it certainly, in its relative alkali percentage, as well as in its percentage of lime, gives no colour for believing that it was derived from sediments of like character. On the other hand, I think there would be nothing improbable in the assumption, at least from a chemical point of view, that it may represent the metamorphosed equivalents of such rocks as (δ) 1, 2, 3, the fragments from the Torridon sandstone, if such rocks were at all of widespread distribution. 9, 10, 14, and probably 5, might readily be explained on such hypothesis.

Gneisses 1, 4, 5, not foliated granites.

Nos. 1, 4, 5, if originally belonging to the acid or intermediate group of igneous rocks, were certainly never anything like typical granites; and consequently, the hypothesis that these examples of gneiss may be foliated granites is not borne out by the analysis.

Corroboration of results by microscope.

Of course, to be of much value as a guide in the determination of the original character of what are now metamorphic rocks, chemical analyses should be supported and corroborated by microscopic examination. But in many such cases, microscopic characters are admittedly not final. I think it is probable that in such circumstances an appeal to both methods—that is, both the chemical and microscopic — may be relied on in the majority of instances to produce decisive results. With this object in view, sections of some of the rocks analysed have also been examined microscopically, and the results, as inferred from the chemical analyses, have so far confirmed, or at least have not been contradicted by, the microscopical examination.

Microscope not final.

Results from chemical analyses generally corroborated by microscope.

One or two remarks of a critical character fall to be made in view of the results of the present paper.

In an address on "Desert Conditions in Britain,"[1] Mr Goodchild says, with special reference to the Torridon sandstones—"The reconversion of the derivative arkoses into granite or into gneisses will be admitted by most geologists to come well within the range of possibility." Comparing the above analyses of Torridon sandstone with those of such gneisses, local and other, to say nothing of granites as have been made, one naturally asks how has the lime, and in particular the soda, been restored during the process of metamorphism? The almost total disappearance of the lime and soda from the Torridon sandstone would also appear to militate against the hypothesis of arid conditions, which he pictures as prevailing in Torridon times.

Reconversion of derivative arkoses into granites and gneisses.

How has the lime and the soda been restored?

Absence of lime and soda against theory of arid conditions in Torridon times.

Further, another result, viz., the demonstration of the complete concordance, so far as chemical composition goes, of the Green Schists of Gairloch with typical basic eruptives, may be taken as making for the realisation of the hope expressed by Sir A. Geikie, in his "Ancient Volcanoes of Great Britain,"[2] "that somewhere there may have been preserved and may still be discovered proof that these eruptive rocks (that is the Archæan intrusives) opened a connection with the surface, and that we may thus recognise vestiges of the superficial products of actual Archæan volcanoes."

Green Schists of Gairloch possible superficial products of Archæan volcanoes.

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[1] "Transactions," Vol. VII., Pt. iii., p. 222.

[2] "Ancient Volcanoes of Great Britain," vol. i. p. 120.

TABLES OF ANALYSES

(α) GRANITES

	Silica SiO_2	Alumina Al_2O_3	Ferric Oxide Fe_2O_3	Ferrous Oxide FeO	Manganous Oxide MnO	Lime CaO	Magnesia MgO	Potash K_2O	Soda Na_2O	Loss on Ignition	$\frac{K_2O}{Na_2O}$	TiO_2	P_2O_5	Cl	TOTALS
1. Benrinnes	74·75	14·08	1·18	·85	Trace	·49	·04	5·39	3·09	·34	1·74	...	·12	...	100·33
2. Abriachan, Loch Ness .	71·25	18·03	1·29	·34	,,	2·61	·38	3·09	2·25	·82	1·37	...	·13	...	100·19
3. Kinsteary, Nairnshire .	69·99	17·75	·49	·17	...	1·67	·13	5·86	3·24	·73	1·95	...	...	...	100·03
4. Peterhead	73·70	14·40	·43	1.49	Trace	1·08	Trace	4·43	4·21	·61	1·05	...	...	...	100·30*
5. Ardclach	73·65	14·28	2·65	...	,,	1·28	·81	3·95	2·51	·65	1·57	...	·15	·05	99·98
6. Granite Vein, Craigellachie Bridge	75·39	13·62	·70	...	...	1·84	Trace	4·39	2·77	1·21	1·58	...	...	...	99·92
7. Granite Vein, Fiddich Bridge, Craigellachie .	77·18	13·78	1·07	...	...	·12	·05	3·27	3·68	·63	·89	Trace	·17	·06	100·01
8. Granite Vein, Archæan Gneiss, Heights of Kinlochewe	76·54	14·09	1·47	...	...	·19	·10	4·64	2·32	·74	2·00	...	...	..	100·09
9. Cairngorm, Northern Front	76·01	13·47	1·54	...	...	·54	·06	5·57	2·32	·56	2·49	...	·12	...	100·19
10. Stratherric, top of Glen Liath	59·34	18·91	6·22	·95	...	3·97	2·55	2·91	2·61	1·43	1·11	·72	·26	·027	99·897
11. Loch Moy, Inverness-shire .	71·42	15·32	3·48	·21	...	1·75	·71	3·65	2·77	·74	1·32	...	...	·066	100·116
12. Ruthrie (Grey), Aberlour .	68·01	17·34	3·66	...	...	2·06	·77	4·41	2·05	·64	2·15	·83	·41	·069	100·249
13. Rubislaw, Aberdeen . .	69·01	17·74	·97	2·05	...	1·95	·48	3·94	2·73	1·18	1·46	Trace	...	...	100·05
Average . .	72·02	15·60	1·93	·46	...	1·50	·47	4·27	2·81	·79	(1·52)	·10	·18	·054	100·234
			2·44 Fe_2O_3										Average of 7	Average of 5	
Average of 11 Granites by Haughton . . .	72·07	14·81	2·22		..	1·63	·33	5·11	2·79	1·09	...	...	...	...	100·05

* No. 4 of the above is an analysis by J. A. Phillips.

(β) DIORITES, &c.

	Silica SiO_2	Alumina Al_2O_3	Ferric Oxide Fe_2O_3	Ferrous Oxide FeO	Manganous Oxide MnO	Lime CaO	Magnesia MgO	Potash K_2O	Soda Na_2O	Loss on Ignition	$\frac{K_2O}{Na_2O}$	TiO_2	P_2O_5	Cl	TOTALS
Netherly Rothes, Morayshire—															
1. Periphery of Boss	58·44	21·43	6·88	·31	Trace	4·84	3·66	1·14	·59	CO_2 ·19 H_2O 2·01	1·90	Trace	·23	·16	99·88
3. Nearer centre .	53·22	16·84	...	9·27	...	8·53	6·48	1·39	3·54	·95	·39	,,	...	...	100·22
2. Centre of Boss .	51·78	19·74	11·20	...	Trace	7·17	4·52	·99	1·76	1·32	·56	·80	07	·18	FeS_2 ·54 100·07
4. Dandaleith, Morayshire . . .	54·09	16·72	...	9·38	·52	8·35	5·58	·97	1·23	2·58	·79	Not det.	·39	·05	99·86
5. Glen Liath, cutting, 6 (δ) . . .	55·68	20·94	3·72	3·09	...	5·07	4·75	1·74	2·49	2·63	·70	,,	·16	·03	100·30
6. Basic Intrusive, Archæan Rocks, N. of L. Marec . .	45·23	18·88	4·49	8·89	Trace	8·77	7·42	·88	1·36	3·60	·65	None	·16	...	99·68
	53·07	19·09	4·38	5·16	·09	7·12	5·40	1·18	1·83	2·21	·64	·13	·20	·105	99·965

(γ) SPECIAL ROCKS OF THE AREA.

	Silica SiO_2	Alumina Ae_2O_3	Ferric Oxide Fe_2O_3	Ferrous Oxide FeO	Manganous Oxide MnO	Lime CaO	Magnesia MgO	Potash K_2O	Soda Na_2O	Loss on Ignition	$\frac{K_2O}{Na\ O}$	Cl	P_2O_5	TiO_2	TOTALS.
1. Diabase Porphyrite Gartly, Aberdeenshire	53·81	20·41	11·45	...	Trace	1·65	1·76	3·72	2·55	3·98	1·46	·05 ·03 ·08	·12	·19	99·78
2. Serpentine, Portsoy .	45·15	·71	...	4·48	,,	4·56	31·91	·22		12·28	...	·10	·81	Trace	100·22
3. Quartz Porphyry, Craigan-oan, Inverness-shire . .	76·74	14·07	1·12	...	...	·23	·16	4·02	2·16	·78	1·86	...	...	...	99·28

(δ) THREE FRAGMENTS (RHYOLITIC?) INCLUDED IN THE TORRIDON, GLEN BANAISDALE, ROSS-SHIRE.

	Silica SiO_2	Alumina Ae_2O_3	Ferric Oxide Fe_2O_3	Ferrous Oxide FeO	Manganous Oxide MnO	Lime CaO	Magnesia MgO	Potash K_2O	Soda Na_2O	Loss on Ignition	$\frac{K_2O}{Na\ O}$	Cl	P_2O_5	TiO_2	TOTALS.
1. With Porphyritic Felspars . . .	74·15	18·13	2·27	...	...	·11	Trace	2·26	1·50	1·47	1·51	...	...	...	99·89
2. Semi-vitreous Variety	64·86	19·40	...	4·33	...	Trace	1·92	4·82	·45	4·29	10·7	...	...	..	100·07
3. Specimen of Intermediate Character .	74·68	11·15	3·36	1·77	·84	2·19	1·52	1·31	1·12	CO_2 ·59 H_2O 1·75	1·16	...	...	...	100·28
Average . .	71·23	16·23	1·88	2·03	·28	·77	1·15	2·80	1·02	2·70	...	...	...	...	100·09

(c) METAMORPHIC SERIES.

	Silica SiO_2	Alumina Al_2O_3	Ferric Oxide Fe_2O_3	Ferrous Oxide FeO	Manganous Oxide MnO	Lime CaO	Magnesia MgO	Potash K_2O	Soda Na_2O	Loss on Ignition	$\frac{K_2O}{Na_2O}$	Cl	P_2O_5	TiO_2	TOTALS
1. Archæan Gneiss, R. Bruchaig, Kinlochewe . . .	64·98	18·30	...	5·42	Trace	1·86	1·39	2·03	3·98	1·84	·51	...	·22	...	100·02
2. Green Schists, Archæan Series, Gairloch . .	47·99	15·32	14·60	2·81	·37	8·19	5·90	·43	1·43	·88	·3	FS ·18	·16	1·81	100·07
3. Younger Gneiss. Glen Docherty, Ross-shire .	80·39	9·26	3·68	...	...	1·02	1·02	1·54	1·18	1·72	1·3	...	...	·27	100·08
4. Gneiss, Daviot, Inverness-shire	56·93	20·49	8·83	...	·61	2·09	2·16	3·70	3·87	1·79	·96	...	...	...	100·47
5. Gneiss, Craig-an-oan . .	68·10	16·99	5·51	...	Trace	3·05	1·07	2·63	1·56	·93	1·69	.	...	...	99·84
6. Gneiss (Clastic Origin), Glen Liath	75·30	13·64	2·88	..	...	·63	·43	4·49	1·53	·71	2·93	·12	...	...	99·73
7. Hornblende Schist, Rothes Burn, Morayshire . .	49·10	14·95	...	14·74	...	9·09	5·04	1·90	1·81	2·20	1·05	·017	·46	·74	100·047
8. Dark Mica Schist, Rothes Burn	56·67	20·25	7·01	...	·64	5·04	1·52	2·54	3·58	1·47	·71	·025	·09	1·45	100·285
9. Dark Mica Schist, same locality	72·48	15·86	3·25	...	...	2·21	·12	2·51	3·18	·53	·79	...	...	...	100·14
10. Quartz-Mica Schist, Rothes Burn	77·37	11·22	2·92	...	...	1·40	·46	2·94	2·31	·95	1·27	...	...	...	99·57
11. Schist under Granite Vein, Craigellachie Bridge .	54·01	22·86	...	7·33	Trace	1·11	1·91	5·12	2·71	3·98	1·89	...	·20	·89	100·12
12. Another Specimen, same locality	75·10	14·23	3·99	...	...	·74	1·08	1·64	1·74	1·62	·94	...	Trace	...	100·14
13. Quartzite, West of Rothes .	96·51	2·02	·77	...	...	·26	·05	·25	·07	·46	3·55	...	...	...	100·39
14. Dark Micaceous Slate, Mulben, Banffshire . .	72·64	11·61	4·86	...	·46	1·20	·98	2·07	2·93	1·35	·71	·010	·22	1·42	99·75
15. Clay Slate, Foudland Hill, Aberdeenshire . . .	56·50	23·14	...	10·37	...	·45	1·33	2·38	1·17	3·92	2·04	S·016 Cl·029	·18	...	99·905
Average . . .	66·94	15·34	3·89	2·71	·14	2·56	1·63	2·41	2·20	1·62	1·1	(Cl·04)	·22	·44	100·14

SANDSTONES.

(*a*) TORRIDON SANDSTONE.

	Silica SiO_2	Alumina Al_2O_3	Ferric Oxide Fe_2O_3	Ferrous Oxide FeO	Manganese Dioxide	Total Lime CaO	Lime as Silicate	Magnesia MgO	Potash K_2O	Soda Na_2O	$\frac{K_2O}{Na_2O}$	Loss on Ignition. Carbonic Acid CO_2	Loss on Ignition. Water H_2O	P_2O_5	TOTALS
1. ( ) Kinlochewe, rough grained	82·14	9·75	1·23	...	...	·15	...	·19	5·27	·50	10·54	·19	·64	·12	100·18
2. ( ) Torridon, finer grained	79·07	10·34	4·36	...	...	·23	...	·04	4·20	·27	15·55	·95		...	99·46
3. Glen Banaisdale, containing Rhyolitic (?) fragments .	65·26	14·45	7·85	...	...	·35	...	2·95	3·29	·32	10·28	5·55		...	100·02
Average . . .	75·49	11·51	4·48	...	...	·24	...	1·06	4·25	·36	...	2·44		...	...

(*b*) LOWER OLD RED SANDSTONE.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO_2	CaO as $CaCO_3$.	CaO as Silicate	MgO	K_2O	Na_2O	Loss on Ignition CO_2	Loss on Ignition H_2O	$\frac{K_2O}{Na_2O}$	TOTALS
1. Tarradale, Black Isle	80·06	7·36	1·41	·43	·36	3.59	·09	Trace	1·57	·27	2·75	2.50	5·9	100·30
2. Foyers, Loch Ness	73·32	11·31	3·54	·72	Trace	1·35	·18	·24	6·16	2·34	·92	·30	2·63	100·20
3. Red Crags, Fochabers-on-Spey .	59·24	6·65	2·02	·31	·50	16·04	·56	·12	2·30	·19	12·16	1·26	12·11	100·79
4. Matrix of Conglomerate Tynet .	51·65	8·81	3·15	...	1·01	18·41	1·68	·33	1·28	·27	13·15	2·40	4·76	100·49
5. Matrix of Conglomerate, Achenroath	71·22	2·55	3·01	...	...	10·27	...	·24	3·02	·25	9·01		12·08	99·58
Average	67·10	7.34	2·63	·29	·38	9·93	·63	·19	2·87	·67	...	...	4·3	...
			2·95 Fe_2O											

(c) UPPER OLD RED SANDSTONE.

	Silica SiO_2	Alumina Al_2O_3	Ferric Oxide Fe_2O_3	Ferrous Oxide FeO	Manganese Dioxide MnO_2	Total Lime CaO	Lime as Silicate	Magnesia MgO	Potash K_2O	Soda Na_2O	Loss on Ignition.		$\frac{K_2O}{Na_2O}$	TOTALS
											Carbonic Acid CO_2	Water H_2O		
1. Seaat Craig	49·74	1·33	1·89	·57	·86	24·52	1·70	·20	1·05	·37	17·93	1·73	2·8	100·19
2. King Steps, Nairn	77·75	8·40	·70	·21	·09	4·25	·75	·41	3·89	·83	2·75	1·09	4·69	100·37
3. Newton, Elgin	85·56	10·76	·52	·23	Trace	1·00	·91	Trace	1·57	·12	·07	·43	13·08	100·26
4. ,, (other specimen)	90·85	6·69	·71	...	...	·23	·23	·08	·97	·07	·53		13·86	100·13
5. Rosebrae, Elgin	92·13	4.42	·37	·33	·24	1·27	1·27	·14	·72	·11	None	·42	6.55	100·15
6. Bishopmill, Elgin	87 00	8·84	·28	...	...	·46	·31	·47	1·78	·23	·12	·62	7.74	100·26
7. Cronstone, New Elgin	19·75	·79	·53	·21	·67	12·39	...	1·08	·82	·12	33·74		6·83	100·10
8. Oakbrae, Elgin	88·20	7·72	·62	...	Trace	·17	·17	·16	1·88	·48	1·03		3 92	100·26
Average	73·87	6·12	·70	·19	·23	9·27	·67	·32	1·58	·29	...		5·44	...
			·91 Fe_2O_3											

(d) REPTILIFEROUS.

	Silica SiO_2	Alumina Al_2O_3	Ferric Oxide Fe_2O_3	Ferrous Oxide FeO	Manganese Dioxide MnO_2	Total Lime CaO	Lime as Silicate	Magnesia MgO	Potash K_2O	Soda Na_2O	Carbonic Acid CO_2	Water H_2O	$\frac{K_2O}{Na_2O}$	TOTALS
1. Cuttieshillock	93·01	3·86	·63	...	...	·32	·17	·28	1·57	·22	·12	·65	7·14	100·54
2. Spynie	89·43	4·00	·39	·36	...	2·21	1·76	·17	1·73	1·35	·35	·15	1·28	100·14
3. Findrassie	77·24	9·47	·54	·20	Trace	5·42	2·06	22	1·05	·39	2·64	2·39	3·	99·56
4. Covesea.	95·41	1·63	·18	0·5	...	·27	None	·03	·75	Trace	·22	1·63	...	100·17
5. Greenbrae ( ) Cumingstone	93·69	1·21	1·11	·15	...	1·14	·80	·16	·98	·26	Fl ·21 Cl ·03 CO_2 ·09	·91	3·77	99·94
Average	89·75	4·03	·57	·15	...	1·87	·96	·17	1·22	·44	...	...	2·76	...
			Fe_2O_3 ·74											

RECENT DEPOSITS.

	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	CaO	MgO	K_2O	Na_2O	$\frac{K_2O}{Na_2O}$	P_2O_5	Loss on Ignition	TOTALS
(*a*) GLACIAL AND SUB-GLACIAL.													
1. Boulder Clay, Morayshire Poor House	80·13	9·06	2·44	...	...	·72	·50	2·08	·66	3·16	·14	4·11	99·84
2. Boulder Clay, Baron's Craig, Rothes	74·89	12.22	4·29	...	·17	1·58	·07	2·64	1·06	2·49	·07	3·21	100·20
3. Foliated Clay, Rothes Burn (sub-glacial ?)	62·42	17 92	5·89	TiO_2 1·62	...	2·01	1·55	3·31	1·36	2·43	...	4·29	100·37
4. Sand 500 ft., Terrace, Drumbain, Rothes	77·78	9·95	2·55	FeO ·21	...	·71	·17	2·50	1·82	1·37	...	2·74	99·93
5. Sand 100 ft., Terrace, Southview, New Elgin	90·74	5·16	1·14	·08	Trace	·69	Trace	1·19	·26	4·57	...	1·30	100·56
Average	77·19	10·86	3·26	·06	...	1·14	·56	2·34	1·03	2 27	...	2·93	...
(*b*) RIVER SANDS.													
1. Deveron, Rothiemay	75·79	9·57	6·33	...	...	2·73	1·81	1·75	·53	3·26	...	1·72	100·23
2. Spey, Craigellachie	83·40	9·42	1·96	...	Trace	1·15	·46	1·43	·79	1·80	·20	·94	99.75
3. Lossie, Elgin	90·27	4·01	1·95	...	·16	·33	·04	1·73	·78	2·22	·11	·44	99·82
4. Findhorn, Dulsie Bridge	81·07	10·59	1·61	...	...	1·15	·25	2·26	1·57	1·44	·29	·98	99·77
5. Nairn, Nairn	80·12	11·59	2·85	..	Trace	1·06	·10	2·48	1·07	2·32	...	·96	99·96
Average	82·13	9·04	2·94	...	..	1·28	·53	1·93	·95	2·03	·20	1·01	...
(*c*) SEA SANDS.													
1. Shore, Lossiemouth	89·99	7·36	·72	·13	Trace	·46	Trace	·84	·33	2·55	...	·60	100·43
2. Balmeannach, Skye (from basic igneous rocks)	55·03	14·12	10·15	...	...	6·88	6·38	1·66	·87	1·97	...	4·55	99·64
Average	...	...	...	...	...	...	...	...	...	2·08	...	...	...
(*d*) BLOWN SAND.													
1. Culbin	91·39	5·44	·89	·16	Trace	Trace	Trace	1.19	·70	1·7	...	·65	100·42

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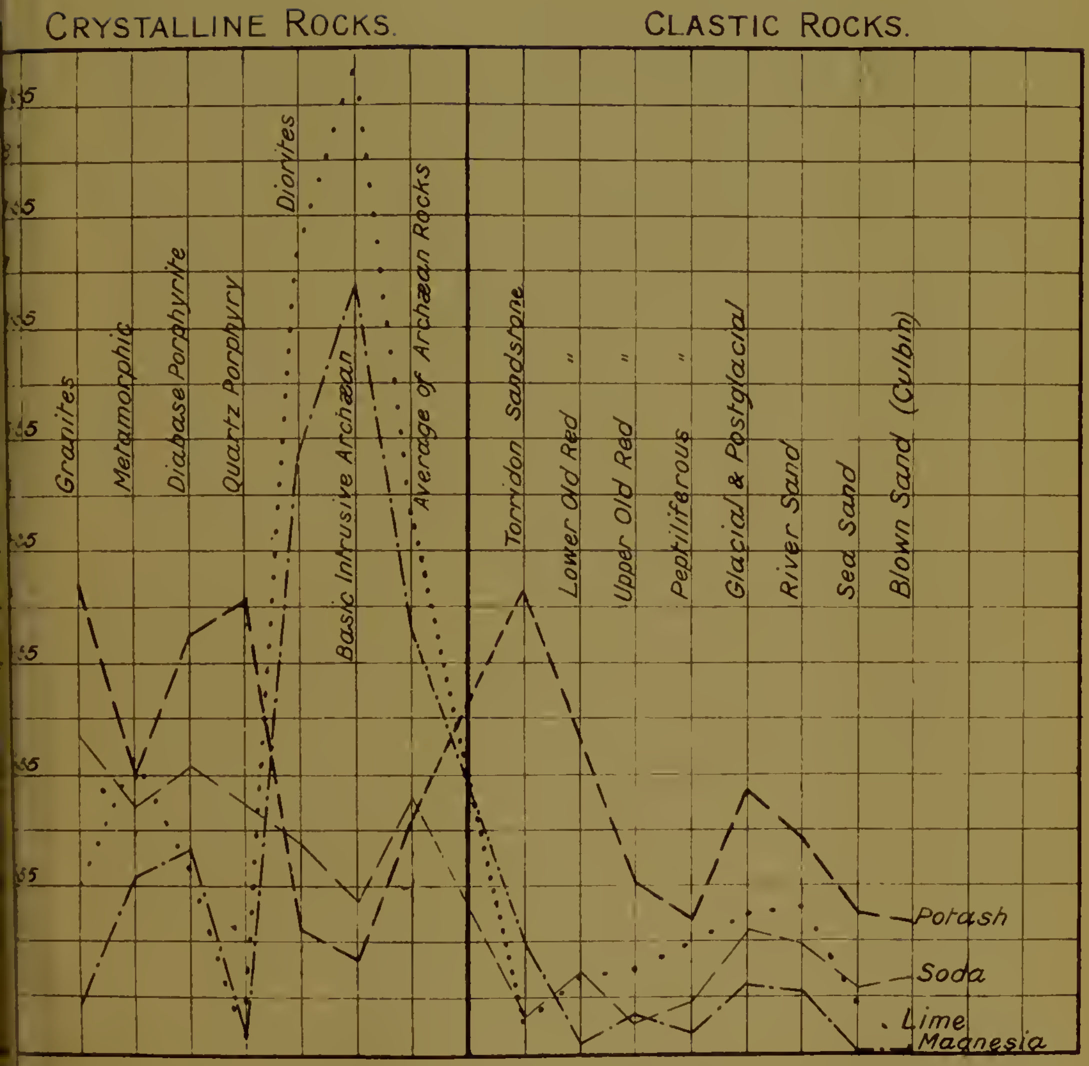

Proportions of Lime, Magnesia, Potash, and Soda in the Crystalline and Clastic Rocks (Graphically Represented).